Japanese Product Quality Revisited

Ravi Durvasula

For the reader-

A total of five (5) papers are presented regarding Japanese Product Quality. These papers are the result of my attempts to understand clearly how Japanese Product Quality results or materializes. Everyone has their own "Eureka" moment or "Darwin" moment and these papers were those moments for me. The papers are listed below:

1. Origins of quality,
2. A Comparison of Japanese and American Products,
3. Components Near Specification Limits,
4. The Source of Japanese Product Quality, and
5. Japanese Product Quality Revisited.

It was in the later 1980s that I first encountered Japanese Product Quality in terms of trying to understand its "Source"; and I was unable to understand it from the writings of several writers, including experts and being an engineer my only recourse was to looking inside Japanese products and understand their components and details. The result was an independent opinion about Japanese Product Quality and its "Origins" with my opinion becoming a living and breathing paradigm that I refuse to let go of even today because of its fundamental importance in designing and making products anywhere. My sincere wish is that yourself and others will improve on this important subject of Japanese Product Quality and the result will become techniques that are of a commonsense nature and of universal ubiquity in their being understood and practiced. I wanted to put these papers together into a second eBook after I had put together a first eBook that would introduce engineering and innovation as everyday things for everyone but then decided to release these papers first as I felt the two items are separate and there are others much more knowledgeable than myself that can take these papers to the next level right away. Please read through these papers and enjoy your "Revisit" to Japanese Product Quality.

With Best Regards.
Ravi Durvasula.

NSF TAKES AFFIRMATIVE ACTION

In its continuing efforts to encourage women, minorities, and persons with disabilities to pursue careers in engineering, the National Science Foundation is awarding grants from its new Graduate Engineering Education (GEE) program to 14 U.S. universities. Awards in the GEE program support students involved in full-time study and research leading to doctoral degrees in engineering. The 14 universities receiving GEE grants will use their allotted $25,000 per doctoral student to support a student's stipend ($15,000), tuition ($5,000), and miscellaneous expenses such as conferences and lab equipment ($5,000). In 1989, 23 blacks, 7 native Americans, and 33 Hispanics received Ph.D.'s in engineering. The GEE grants specify that at least 43% of the 85 fellowships awarded go to these underrepresented minorities. The remaining awards will be available for women. Only 8.2% of engineering Ph.D.'s awarded in 1989 were earned by women. ■

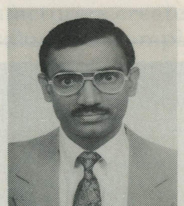
LAN EXPENSES KEEP GROWING

U.S. businesses will spend $51 billion annually on local-area networks (LANs) by 1995, according to a report by Frost & Sullivan, a New York City-based consulting firm. In 1989, companies spent $9.2 billion to keep their LANs up and running. By 1990, that figure grew to $12 billion. The largest portion of this money has been for hardware maintenance. In 1989, $2.7 billion went to maintenance; in 1990, $3.4 billion. By 1995, installation, including cabling and LAN start-ups, will be the largest LAN-related expense. From less than $2.2 billion in 1989, it should increase to $14.5 billion by 1995. Another major expense is moving and modifying existing LANs. A $2 billion market in 1990, it will represent $6.9 bilion by 1995. Education and training costs are going up as well. Where $1 billion was spent in 1989, $1.3 billion was spent in 1990, and $5.9 billion is expected to be spent in 1995. ■

VANTAGE POINT

Origins of quality

RAVI DURVASULA



It is a given in many circles that Japanese products are superior in quality to those made in the U.S. But few people are willing to say whether the high degree of quality comes from better workmanship, better engineering, or a totally different approach to product design. To satisfy my own curiosity as to the origins of Japanese quality, I applied some engineering knowledge and common sense to analyzing similar Japanese and American products.

The Honda Accord automobile, manufactured in both the U.S. and Japan, routinely garners high praise from those who purchase it regardless of which factory built it. This seems to indicate that customer satisfaction, a good measure of quality, was designed into the Accord and does not depend on the skill of the workers assembling it. Another example is that of a plant in England manufacturing both the Sterling and the Acura. The Acura enjoys an excellent reputation among its owners while the Sterling does not, even though both cars are made by the same workers. Again, evidence points to design as the key to quality.

To further understand design differences between U.S. and Japanese engineers, I compared the 1988 Ford Tempo to the Honda Accord, two cars of roughly equal size. The Accord, despite a smaller and lighter engine and body made of thinner sheet metal, still weighs nearly as much as the Tempo. The Tempo weighs 2,600 lb compared to the Accord's 2,590 lb. This leads me to believe the Japanese-designed car uses more metal parts than the American one.

Comparing two electric relays with similar performance characteristics, one American, the other Japanese, also shed light on Japanese design philosophy. The American relay weighed 80 gm and was made up of 58 parts, 50 metal and 8 plastic. The Japanese relay weighed 87 gm and had 92 parts, 73 metal and 19 plastic. The Japanese relay used more parts as spacers and fasteners indicating intentional float, or adjustability, in assembly to allow for loosely toleranced parts.

From these comparisons, the following conclusions were drawn:

- Japanese products have higher parts counts and use more metal than their American counterparts. More parts, using more metal parts, and adjustability of assembly increases tooling and manufacturing costs for Japanese products and makes them assembly intensive.
- Adjustability in assembly points to the capability of the design to work well with loosely toleranced parts.
- Higher parts counts and loosely toleranced parts, traditionally associated with poor reliability and low quality, can be integrated with adjustability in assembly to come up with designs for high-quality, dependable products. On the other hand, American engineers rely on lowered parts counts and tighter tolerances to produce quality goods.

Most Japanese design practices I discovered in my search for quality's origins are similar to those spelled out in books written by Genichi Taguchi, a Japanese quality guru. Whether or not his methods are better than American design practices is impossible to say. Both approaches are acceptable if the finished product preforms reliably in the field and the customer can afford it. For the past 10 years, Japanese companies have been competing with American manufacturers on the basis of dependability. The challenge, then, is for American companies to continue in their methods and increase product reliability and dependability, or to change their methods. ■

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Do you have an opinion or observation on some aspect of engineering you would like to share with other readers? If so, please send us a copy, about 800 words in length. Mail to Personal/Professional Editor, c/o MACHINE DESIGN, 1100 Superior Ave., Cleveland OH 44114-2543.

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A Comparision of Japanese and American Products

Srinivasa Ravi Kumar Durvasula

USA

Paper Th B 08

A COMPARISON OF JAPANESE AND AMERICAN PRODUCTS

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Similar Japanese and American products are compared and the conclusions are that Japanese manufacturers put quality into their products primarily through design and Japanese products typically have higher parts count, and have greater emphasis on usage of metal than similar American products. Examples from Dr. Taguchi's methods seem to confirm these conclusions.

I have compared Japanese and American products using a commonsense approach and some engineering knowledge, to understand, by observing some things about Japanese and American products, what the Japanese could be doing to put quality into their products. From these observations, I concluded that manufacturing is not the prime suspect in understanding Japanese product quality, and that Japanese products have greater emphasis on usage of metal in parts, higher parts count, and adjustability during assembly, compared to their American counterparts. Dr. Genichi Taguchi's(Japanese) methods contain examples of products which confirm these conclusions about Japanese products.

The Honda Accord is made both in Japan and the USA. Despite any deficiencies in craftsmanship at the American Honda factory, the customer satisfaction of the Accord is excellent. The Sterling and the Acura(European market) are made on the same assembly line in England. The Acura enjoys excellent customer satisfaction while the Sterling does not. These are examples of manufacturing situations, where the Accord example is one of the same product made in different factories with different workers, and the Sterling and the Acura examples are of different products made in the same factory with the same workers, eliminating manufacturing as the prime suspect in understanding what the Japanese do to put quality into their products.

Similarly equipped, the 1988 Ford Tempo and the Honda Accord are almost the same size and weigh almost the same. The Tempo weighs 2600 lbs. and the Accord weighs 2590 lbs. The Accord has a 2.0 liter engine(lighter than the Tempo's 2.3 liter engine). The Accord will have thinner(and hence lighter) sheet metal in its body. The Tempo will have a lot of emphasis on plastic(and hence lighter parts) as it is the norm of American industry. Drawing upon such differences between the Accord and the Tempo, I think that the Accord should have emphasis on metal in parts to approach the Tempo's weight.

Next I compared two interchangeable relays, one Japanese and the other American. The American relay weighed 80 gms. and the Japanese relay weighed 87 gms. approximately. There were 92 parts total in the Japanese relay(metal:73 parts and plastic:19 parts) and 58 parts total in the American relay(metal:50 parts and plastic:8 parts). The Japanese relay had many fasteners (screws with lock washers) in it. Out of the 19 plastic parts in the Japanese relay, except for the relay housings(2 parts) and coil bobbin(1 part), 5 parts were used as spacers and insulators, and 11 parts were wire insulations. In addition to securing an assembly, the use of fasteners also allows for adjustments in the assembly to hold and maintain the interface between components, in this case; the alignment of the relay contacts and their air gaps. This would also point to float in the assembly. The contact buttons in the Japanese relay had more material in comparison to the American relay. The American relay had bare(uninsulated) wires connecting to its pins.

After comparing Japanese and American products thus, I formed the following opinions about Japanese products.

1) Japanese products probably have higher parts count, and more emphasis on the use of metal in parts than their American counterparts. Higher parts count, emphasis on usage of metal in parts, and adjustability of the assembly make Japanese products assembly intensive and more expensive to tool up and manufacture than similar American products.

2) Adjustability and float in the assembly point to the capability of the design to live with loosely toleranced parts. Higher parts count(lowered reliability) and loosely toleranced parts(lowered quality) can be integrated into a design package, along with adjustability of the assembly to produce dependable products. Such a scenario could also explain Japan's success in its off shore manufacturing as the Accord and Acura examples mentioned earlier show.

3) As mentioned earlier, with manufacturing eliminated as the prime suspect in understanding Japanese product quality, Japanese products and their designs must be studied thoroughly and critically in order to identify features in them that result in excellent field performance and customer satisfaction.

In his book, "Introduction to Quality Engineering", Dr. Genichi Taguchi mentions examples that support my conclusions about Japanese products. Parameter design, is the second step in Dr. Taguchi's methods, where, using low cost and high variability components, studies are done to optimise the settings(parameters) of the components to realise products that perform consistently with little variation about their targeted performance. In

tolerance design(final step, and best when done after parameter design), some components of the parameter design may have to be replaced with low variability and higher cost components if the product's targeted performance is not accomplished by parameter design. During production, products are tested and if they deviate from their target requirements, they are adjusted to meet those requirements.

In a parameter design example, a television circuit to convert 100 VAC to 115 ± 1.4 VDC(target) is studied showing that the inexpensive transistor had a parameter that varied ±30% from its nominal, and the output voltage varied from 122 VDC to 127 VDC. Next a resistor is added to the circuit to bring down the output voltage to the target. In production, the target varies from 122 VDC to 127 VDC and each time the target is brought down to 115 ± 1.4 VDC by adding a resistor. The American approach would have been to use a low variability transistor to increase the precision of the output voltage about 115 VDC directly, adding cost to the component, often more expensive than using a low cost transistor with an extra resistor. This approach of Dr. Taguchi points to the use of as many parts as needed to make the best use of the low cost components. In an example about on-line quality control, he mentions that adjustments to target are done automatically by robots during production meaning that even adjustments of the product to target during assembly can be automated, without involving people. These examples support the conclusions about Japanese products having more parts than similar American products and adjustability of the product during assembly.

Dr. Taguchi also encourages the use of over-design. In an example for a pipe joint to meet a minimum strength requirement of 12 kg.(27 lbs.), his methods require that the pipe joint meet a minimum strength of 98 kg.(216 lbs.). He encourages using different materials, changing shape or increasing the thickness to meet this requirement. The American approach would have been to have the pipe joint meet a minimum strength of 15 kg.(33 lbs.) so that the minimum requirements of 12 kg.(27 lbs.) are met. The pipe joint example indicates that due to over-design, Japanese products probably weigh more than their American counterparts, and also from this approach to over-design, emphasis on usage of metal in parts follows.

Japanese products, then, according to Dr. Taguchi's methods, have low cost and high variability components, adjustability of the assembly, over-designed components for stable and reliable performance, and no limitations on the number of parts to be used in achieving the required functions and targeted outputs, which supports my conclusions about Japanese products earlier.

In general, Japanese products have better reliability and quality than similar American products, even though they have higher parts count which should lower reliability, and loosely toleranced parts which should lower quality; while American products have lower parts count and tighter tolerances. In theory

Japanese products should have lower reliability and quality than American products. But in practice this is not so.

During parameter design in Dr. Taguchi's methods, a stable and consistent output product is designed, no matter the parts count. The product will work even though the components are low cost and high variability because of derating. Derating is an over-design condition of manufactured components where the component is seldom stressed beyond 15% of its capacity in operation in the product. Derating is necessary because, otherwise the component manufacturer will not be able to make components that can be sold to customers. Hence Japanese manufacturers do not worry about the higher parts count because the parts will work and the problem becomes one of integrating the components into a stable and consistent output product and this is accomplished by good parameter design. Adjustability of the product during assembly helps in taking the products to their targeted performance levels as mandated by parameter design. Thus it is possible to make dependable products with high parts count and loosely toleranced parts.

The question arises then, as to which approach is the best, American or Japanese in designing products. The answer is that both approaches are acceptable as long as the product performs reliably in the field and the customer can afford it. I think that Japanese manufacturers are competing with American manufacturers in product dependability. The challenge, then, is for American manufacturers to continue what they are doing and make their products more reliable and dependable in order to compete better with Japanese manufacturers.

References(general)

1) Consumer's Reports 1988 Annual Auto issue.

2) Dr. Taguchi, Genichi, "Introduction to Quality Engineering". Published by Asian Productivity Organisation, Tokyo, Japan.

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VOLUME 1
KEYNOTE ABSTRACTS AND TUESDAY WORKING SESSIONS

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Components Near Specification Limits

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Paper Tu C 10

COMPONENTS NEAR SPECIFICATION LIMITS

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It is shown within a conceptual framework that maximum performance in products results from the presence of components near specification limits. The relationships between quality and reliability, and product performance and quality are reviewed.

Introduction

The usefulness of components near specification limits is a subject of debate in quality(1). The decision is to reject such components and accept those that are near the nominal specifications. The reliability of a product is assured through its design integrity where the proper materials and component details are specified. Quality is ensured at the design stage by the specification of manufacturable components, and in production by the components being made to specifications. Ensuring a product's quality ensures its reliability. Once a product's quality and reliability are ensured, its performance depends on its quality, because variation in component sizes and materials results in variation in performance.

This paper discusses components and their specifications in a conceptual manner and by basic examples and analysis shows that using components at specification limits results in maximum performance in products. The relationships between quality and reliability, product performance and quality are also reviewed.

Quality and Reliability

Quality is concerned with products, components, and materials being made to specifications. Reliability is concerned with life testing of a product which may show failures during its operation. Both quality and reliability are addressed at the design stage. Specification of manufacturable products and components ensures quality. Design integrity of products and components along with the selection of correct materials ensures reliability.

It is possible for a product to fail and have all of its components made to specifications. Design integrity of the product and its reliability are the issues here and not its

quality. If on the other hand some components in the failed product were not made to specifications, both quality and reliability are the issues. When a product has design integrity and is manufacturable, ensuring its quality ensures its reliability.

Product Performance and Quality

When the reliability of a product has been assured through its design integrity, the product's performance depends on its quality. Quality here means that the product's components are manufactured within specifications. As an example, consider an undamped spring-mass system. Its performance can be described in terms of its response, which is its natural frequency of vibration. The natural frequency varies with variations in the weight of the object suspended and the spring rate. These are quality parameters related to the material consistencies of the object and spring materials, and the size of the object, and the wire and coil diameters, and length of the spring.

For a hole(diameter .249 in. +.002, -.000 in.) and a shaft (diameter .248 in. +.000, -.002 in.), the clearance is .003 in. ± .002 in. The performance of the hole and shaft assembly can be defined in terms of the clearance between the hole and the shaft when the parts are made to specifications(materials, surface finishes etc.,). The minimum clearance is .001 in., resulting in a tight fit, and the maximum clearance is .005 in. resulting in a loose fit. In some instances it is desirable to have a tight fit and in some other instances it is desirable to have a loose fit between the shaft and the hole, and the maximum performance of that assembly has to be defined accordingly, in terms of either the minimum clearance or maximum clearance.

Consider the cylinder and piston/piston ring interface in an internal combustion engine. The piston rings provide an effective seal against the leakage of the fuel-air mixture past the cylinder walls. If the fit(defined in terms of oil and fuel-air mixture leakage, and allowing movement of the piston) between the piston rings and the cylinder walls is maximum, then the fuel-air mixture is trapped in a minimum leak condition and the combustion of the mixture results in maximum power output. If the fit between the piston rings and cylinder walls is minimum, then the power output is minimum. Also in this condition of minimum fit, engine oil will find its way into the combustion chamber.

The performance of a product depends on its quality, once reliability is ensured. Component interfaces, such as the cylinder and piston/piston ring interface in the previous example and its fit are responsible for product performance, in this case, the power output of the engine. The interface itself is influenced by the sizes and material consistencies of the individual components, which are quality parameters. Thus product performance is dependent upon quality(sizes and material consistencies of the components).

Consider once again the hole and shaft example. The nominal clearance is .003 in. If both the hole and the shaft came in pairs of minimum, nominal, and maximum dimensions, the clearance in all three cases would be .003 in. which is the nominal clearance, resulting in nominal performance. The maximum performance, however, is defined, depending upon the application by either the minimum or maximum clearance of .001 in. or .005 in. respectively, resulting in a tight or loose fit. Thus nominal performance of a product can be achieved if all of its components were at either the lower specification limits or the higher specification limits, and not just the nominal specifications, in terms of component sizes. Also for a given product and its design, following the above line of thought, it is possible to achieve a maximum performance level beyond which it is either uneconomical or impossible(with the manufacturing processes and design combination) to increase the performance level. Finally, the deterioration of product performance in time, assuming normal usage(wear and tear) will be from maximum performance to nominal performance to minimum performance levels, and this deterioration could be linear or non-linear.

Components near Specification Limits

Nominal performance in products is not just the result of all components in a product at nominal specifications, but also takes place when all the components are at the minimum specifications or at maximum specifications, in terms of component sizes. Components near specification limits are not useless as it is usually concluded, but are useful in realising maximum product performance, as shown earlier. During product design, the interactions between the product's components with sizes on the opposing ends of the specification limits should be studied in order to identify and define conditions within the product that result in maximum performance. The specifications for component sizes should be such that in the worst case assembly, the product has minimum performance, and meets the customer's requirements, and in the best case assembly, maximum performance is achieved. This is because it is realistic to expect variation in component sizes, and the objective is to meet or exceed customer requirements in terms of product performance. Also from this discussion of components near specification limits, it follows that nominal performance as it is usually understood, meeting customer requirements will no longer be the design intent, but minimum product performance, meeting the customer's requirements will be.

Conclusion

It has been shown within a conceptual framework that maximum performance in products results from the interaction of components at opposing ends of the specification limits, in terms of component sizes. Thus components near specification limits are useful and not useless. Product design and manufacturing goals should be to use all the parts made to specifications, including

the ones near specification limits because these result in maximum product performance.

Reference

Chang, T. H.; DeVor, R. E. "Statistical Methods for Quality and Productivity Design and Improvement". Tool and Manufacturing Engineer's Handbook, Volume IV, Chapter 2.

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QUALITY - THE BRIDGE TO HARMONY AND PROSPERITY

PAPERS & ABSTRACTS

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JERUSALEM

THE SOURCE OF JAPANESE PRODUCT QUALITY

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ABSTRACT

Despite Japanese product quality being studied extensively the world over, especially in the United States, its source has remained elusive. Unless what causes Japanese products to have their outstanding quality is identified, all efforts to compete with Japanese products in terms of quality are futile. Does the source lie in the use of Taguchi methods? Is Design of Experiments the correct answer? The answer to both questions is no. This is because these two approaches only present the parameters of the product and are only half the solution. The other half of the solution is in the work of the Japanese design engineer in creating the component details that ensure those parameters in every product made so that there is little variation from nominal performance during the product's usage in the field, and between products.

Japanese product quality originates primarily in design. Take the case of the Honda Accord automobile that is made in both the United States and Japan. Despite the recent Japanese comments about American workers, the customer satisfaction of the Honda Accord is high whether it is made in Japan or in the United States. Take the case of the Acura (European market) and the Sterling. Both cars are made at the same factory by the same workers. The Acura enjoys high customer satisfaction while the Sterling does not. The first example is one of the same design made in two different factories, and the other one is of two different designs made in the same factory. These two examples eliminate manufacturing as the prime suspect in understanding Japanese product quality.

With design identified as the cause of Japanese product quality, the next question is - what exactly is done in design to create Japanese product quality? The answer to this question is found in understanding the writings of Dr. Taguchi, and looking for evidence of his concepts in Japanese products. Such a journey reveals that what Dr. Taguchi spells out as product requirements - high reliability, stable and consistent performance over widely varying conditions in the field, using inexpensive and highly variable components is indeed present in Japanese products but is not created due to Dr. Taguchi's methods alone. Rather it is the work of the Japanese design engineer. Dr. Taguchi calls his process of finding the parameters for the product as "Parameter design research". I have borrowed that phrase from Dr. Taguchi, and I call the work of the Japanese design engineer as "Design research", work that comes after Dr. Taguchi's methods recommend the parameters. It is this work - "Design research" that is the source of Japanese product quality.

In this paper I am presenting examples of design research that I have seen in Japanese products such as magnetic disk drives, and small ac synchronous motors. The discussion is of a general nature so that everyone can understand what the Japanese are doing to create quality in their products.

INTRODUCTION

Since the 1980s, quality has become a subject that has had more questions than answers. Japanese product quality in particular has been the subject of study worldwide, especially in the United States of America (United States, USA, US, America(n) etc.). The source of Japanese product quality still remains elusive for those outside Japan. Japanese product quality in the USA has been studied primarily by statisticians, and Japanese manufacturing techniques have also been studied along with quality. The studies by the former have resulted in wholesale recommendation of the adoption of Design of Experiments (DOE) techniques with or without Taguchi (Dr. Genichi Taguchi, the Japanese quality guru's) Methods. Studies of Japanese manufacturing techniques have resulted in Just in time (Kanban), quality circles (originally an American idea), and more emphasis on teamwork etc., being adopted by American manufacturers. All these things show a willingness on the part of American manufacturers and experts to learn what is being done by the Japanese manufacturers to create better quality in their products, and is perhaps the single most important thing, all by itself.

Neither DOE nor Dr. Taguchi's methods are sufficient by themselves to create quality in products. Improving the manufacturing techniques does improve quality, but it is comes second to design in the process of realizing products. This is because no matter how good the manufacturing is, poor design in the product destroys everything. The reverse is also true - poor manufacturing destroys good design.

JAPANESE PRODUCT QUALITY ORIGINATES IN DESIGN

Japanese product quality originates primarily in design. Take the case of the Honda Accord automobile that is made in both the United States and Japan. Despite the recent negative Japanese comments about American workers, the customer satisfaction of the Honda Accord is excellent whether it is made in Japan or in the United States (by US workers). Take the case of the Acura (European market) and the Sterling. Both cars are made at the same factory by the same workers in England. The Acura enjoys excellent customer satisfaction while the Sterling does not. The first example is one of the same design made in two different factories by different workers, and the second one is of two different designs made in the same factory by the same workers. These two examples eliminate manufacturing as the prime suspect in understanding Japanese product quality. One thing to note about the customer satisfaction of these cars is that it is evaluated by both the J.D. Powers (1) group (short term data), and the Consumer Reports (2) magazine independently (long term data).

The manufacture of Japanese products in the US is carried out in the so-called "transplants". Here Japanese designs are made by American workers. Other examples from the automobile industry (American market names) of Japanese designs made in America are - Toyota Corolla, Nissan Sentra, Mazda 626 etc. A joint production is the Geo Prizm, a hybrid American & Japanese car, that also shows up as an excellent performer in the surveys of the Consumer Reports magazine.

With design identified as the primary factor in Japanese product quality, the question becomes one of where to start. One starts with understanding Dr. Taguchi's writings, as he explicitly states that he is concerned primarily with designing quality into products, what he calls "off-line quality control". Dr. Taguchi is the only Japanese quality expert that talks about designing quality into Japanese products. The next step would be to look in Japanese products to see if indeed Dr. Taguchi's concepts are present in them, and to understand what the Japanese design engineer is doing. This process leads us to the source of Japanese product quality - a technique that I wish to term as "*Design Research*", borrowing the words from Dr. Taguchi's own phrase "Parameter Design Research". What I mean by "Design Research" is completely different from what Dr. Taguchi means by "Parameter Design Research".

JAPANESE PRODUCT DESIGN PROCESS

According to Dr. Taguchi (3), the goals of product design are to create products that have high reliability, stable and consistent performance over widely varying conditions in the field, using inexpensive and highly variable components. American design engineers will agree with these goals except for the use of "highly variable components" as the American attempt to realize overall product quality is by decreasing the variability of the individual components.

The Japanese product design process as one would read it in the literature is outlined below. The initial product design process is generally no different from the one in the United States. Component details, parameters and specifications are worked out. This initial design can then be refined using Dr. Taguchi's methods, which are based upon DOE techniques, and result in the recommendation of parameters for the product, that if *ensured* to be consistent, will result in consistent product performance, with little variation from the design goals, and from product to product. I will not attempt to explain DOE techniques, and there are several statistics books that can do a better job of it. It is sufficient for this discussion to recognize that DOE techniques can be looked upon as an optimization process which yields the nominal values of the parameters of the product. As mentioned earlier, these parameters need to be as close as possible to the nominal values in every product made, if the products are to have consistent and stable performance in the field. DOE techniques are no stranger to American quality practitioners, and two of Dr. Taguchi's

prominent critics in the United States, Drs. George E.P. Box, and Soren Bisgaard, both at The Center for Quality and Productivity Improvement, University of Wisconsin, Madison, Wisconsin, have concluded that Dr. Taguchi's methods are not statistically sound, are cumbersome, and that there are easier and alternative DOE techniques that have been used in the United States all along. The problem with both Dr. Taguchi's methods, and the alternative DOE techniques is that they result in only recommending parameters for the product, and are both only half the solution to the product quality problem. There still remains the more difficult and important issue of ensuring those parameters, which involves component design and details, something that the design engineer has to resolve. This work of the design engineer, which comes in addition to the initial product design and details, is what I am referring to as "design research", while Dr. Taguchi calls finding the parameters as "parameter design research".

WHAT IS IN JAPANESE PRODUCTS?

There are two examples that Dr. Taguchi gives that give us an idea as to what we can find inside Japanese products. In one example, the parameters of an inexpensive and highly variable transistor in conjunction with an inexpensive resistor were studied in attempting to realize a stable and consistent voltage of 115 ± 1.4 VAC, as opposed to using a single low variability transistor. The single low variability transistor would have been the preference among American design engineers. In another example, his loss function analysis recommends that the strength in a pipe joint be increased by a factor of 8, requiring increased pipe thickness and/or change in shape. The transistor example requires testing every assembly, and adjusting the voltage within the target of 115 ± 1.4 VAC because of the high variability of the components. The pipe joint example points to overdesign. The American design engineer would have settled for an overdesign condition of 3 to 4. Both adjustability and overdesign are found commonly in Japanese products. It is necessary to emphasize at this point that Japanese design engineers would not recommend overdesign everywhere in the product - only in critical areas.

The author had examined electric relays, one made in the US, and the other one in Japan (4) and found that the Japanese relay contained more parts than the American relay. There was also adjustability and overdesign in critical areas of the relay - slots and fasteners in the arms to align the contacts as opposed to an one-piece molded sub-assembly with the possibility of contact misalignment during molding, more contact material. Even the restoring spring had a more stable configuration than the corresponding spring in the American relay - bigger wire and spring diameters. From this point on, the rest of this paper will focus on design research.

DESIGN RESEARCH

Let us look at two examples that I have seen in Japanese products - one in magnetic disk drives, dealing with variation in performance as well as procurement, and the other one in small ac timing (synchronous) motors, dealing with potential field failure, so that we can gain an insight as to what the Japanese design engineer was trying to accomplish.

The read/write head system in a disk drive has a spring that has to deliver a load of 15 grams, and that this could be the recommended parameter from a DOE study. The specification in the magnetic disk drive industry is 15 ± 2 grams, and the normal American practice is to design a spring that delivers the load between 13 and 17 grams, resulting in acceptable but varying data read/write performance. The challenge of consistent data read/write performance requires the load to be in a narrower range like 15 ± 0.5 grams. The Japanese disk drive had a spring that had a softer spring rate, and could accomodate larger variations in the spring parameters, and still deliver a load closer to the nominal value. That spring would have delivered a load close to the nominal value, even if it had a coil missing in it. Of course the spring in the Japanese disk drive was compared to the spring in the American disk drive, and was found to be larger in terms of spring diameters, and longer. Once designed, the Japanese spring could be procured from anywhere, and would not have to be inspected. If there was a coil missing in the American designed spring, it simply would be too stiff for the application and would not work.

The weakest portion in ac timing motors is the plastic materials for the gears. Japanese design engineers specify coils for these motors to have more turns than the typical American design engineer would have specified because the result would be a cooler motor that is good for the strength of the plastic gears. There is lesser heat buildup due to the lesser temperature rise in the coil with more turns.

While these are only two examples, and simple ones at that, they show how some critical areas in products have been addressed so that the performance in the field is better - more consistent data read/write, and longer life and heavier load carrying motors. These examples are what I call as examples of "design research", coming after all DOE and Dr. Taguchi's analyses, and represent the contributions of the Japanese design engineer to Japanese product quality.

So what are design engineers to make of all this? The only thing that will disturb design engineers is overdesign in Japanese products. I will mention here once again that Japanese products have overdesign in them only in critical areas and not everywhere. Hopefully, design engineers will come up with something that will help their products become better than Japanese products, and the frist step in that process is thoroughly understanding why the Japanese design engineer is doing what he/she is doing. In understanding Japanese products and their designs, one must keep in mind that product quality is only one of the issues that the Japanese design engineer has to deal with, just like design engineers everywhere else.

While Japanese product design has not been a subject in the public domain, design research, as I am referring to it has stayed in Japan and has not been scrutinized at all by experts anywhere. Drs. Box and Bisgaard have studied Dr. Taguchi's methods and concluded that there are easier and more elegant techniques that can be applied more effectively. It is not unreasonable to expect that the same could materialize about design research. American design engineers and manufacturing have sought to reduce the variation in the individual components in order to reduce the variation in the overall product. Japanese design engineers, on the other hand have allowed for the use of high variability components in their products and succeded better than their counterparts in creating consistent products. The challenge for design engineers everywhere is to explore design research and learn from it to see if they can do better than their Japanese counterparts.

CONCLUSION

Japanese product quality has been identified as originating primarily in design. Specifically, within design, design research has been mentioned as causing Japanese product quality. The words "design research" have been borrowed from Dr. Taguchi's words "parameter design research" and the two are completely different. Dr Taguchi's methods, as well as the DOE techniques are only half the quality story. They both result in only recommending parameters for the products. Those parameters need to be ensured every time, and in every product, and this represents additional work, beyond the initial design of the product, to which the techniques are applied to determine the parameters for consistent performance. This additional work is done by the Japanese design engineer, and this is what I am calling as "design research". The challenge for design engineers everywhere is to explore and understand design research, and come up with better designs for their products.

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THE TENTH INTERNATIONAL CONFERENCE OF THE ISRAEL SOCIETY FOR QUALITY

November 14 - 17, 1994
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5.13
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Power of QQplot in Analysis of Fractional Factorial Experiments
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Analysis of Means to Analyse Experimental Designs with Missing Observations
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Graphical Methods for the Presentation of Factorial Experiment Results
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Japanese Product Quality Revisited
R. Durvasula, Consultant, U.S.A.

Quality by Design: A Review of Taguchi's Parameter Design Experiments
D.M. Steinberg, Tel Aviv University, Israel

Stratified DOE Implementation for Wave Soldering Process
R. Florescu, E. Glushkovsky, V. Gins, Telrad, Israel

Quality Assurance of Data
M. Snyder, Tadiran, Israel

7.13
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Y. Mikhlin, Y. Segal, Technion, Israel

Improving Pyrotechnic Design by use of Statistically Designed Experiments: A Case Study in Quality Improvement
B. Milman, Taas, Israel

Application of a Full Factorial Design for the Development of a Prediction Model for Surface Roughness
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Validity of Supplier and Consumer Sampling Plans, Qstat and Blustat Software Packages
V. Lapidus, M.I. Rozno, Russia

ISO 9000 AND QUALITY AUDITS
ISO 9000 ומבדקי איכות

5.2
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Where is the ISO 9000 Series Heading?
J. Lamprecht, , U.S.A.

The Underestimated Human Influence on ISO 9000 Quality-systems
S. Bremmers, Bremmers Consultancy, The Netherlands

ISO 9000 Built for Improvements
B. Sandell, Halmstad University, Sweden

Preparing for ISO 9000 Assessment
Roger Smith, Bureau Veritas Quality International, United Kingdom

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L. Fox, Objectives International, Inc., U.S.A.

Avoiding the Sand Traps of ISO 9000
G. Cohen, , U.S.A.

The Role of National Research Centers in the World of ISO 9000 ff and EN 45001
D.I. Roggenbauer, Austrian Research Centre Seibersdorf, Austria

The International Quality Rating System (IQRS) Bridging ISO 9000 and TQM
Y. Dror, Det Norske Veritas Industry Inc., U.S.A.

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Certification of Quality Management Systems in Germany
U. Luebbe, Fraunhofer Institute for Manufacturing Engineering and Automation, Germany

Auditor Training
A. Ezrakhovich, Standards Australia Quality Assurance Services, Australia

Planning for ISO 9000 Registration: Internal Audits - How to Get and Keep Your Registration
P.J. Armstrong, R.V. Armstrong & Associates, U.S.A.

The Development of Accredited Quality System Certification in Europe - Are there Lessons to be Learned? Passport or Barrier to Trade?
Ian Day, BVQI - Bureau Veritas Quality International, France

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עדכון תקני ISO 9000 מהדורת 1994
א. כהן, מכון התקנים הישראלי, ישראל

JAPANESE PRODUCT QUALITY REVISITED

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ABSTRACT

Design of experiments & Taguchi Methods result in parameter values which are only half the answer to the product quality and performance problem as component details to deliver those parameters in a consistent and stable manner still need to be worked out by the design engineer. Design is the source of Japanese product quality. Japanese product design philosophy appears to be the integration of inexpensive and highly variable components into stable and consistent performance products. Japanese design engineers' work is called "design research"; words borrowed from Dr. Taguchi's expression "parameter design research" used in his optimization studies which are different from the design engineer's work of component details.

The design of a compression spring is presented where two springs are designed to deliver a load of 1 lb. with 0.3 in. compression - one has a higher stress than the other. The higher stress spring is then refined by increasing the number of coils and spring diameters so that the stress is lowered and the spring functions even if a coil is missing (one coil missing renders compression springs useless). This refined spring then is compared to the second spring which though it had a lower stress would not function with one coil missing.

INTRODUCTION

Since 1980, quality; and Japanese product quality in particular have been the subject of a lot of research and debate both in the United States of America and rest of the world. I do not think any other subject has been scrutinized so much by persons everywhere. Attention was focused upon Japanese manufacturing techniques *(just-in-time, lean production etc.)* and Dr. Taguchi's methods *(orthogonal arrays, loss function, and signal-to-noise ratio)*, and not to Japanese product design issues such as product and component details. Dr. Taguchi's methods result in values of parameters for products and they constitute only half the solution to the product quality problem during product design. The other half of the solution consists of realizing consistent and stable values of those parameters in every product made and is solved by the product design engineer through product and component details.

JAPANESE PRODUCT QUALITY

Japanese product quality originates primarily in product design (1, 2). The Honda Accord automobile is made both in the United States of America and Japan. The customer satisfaction of the Honda Accord is excellent whether it is made in Japan by Japanese workers or in the United States by American workers. The Acura automobile for the European market and the Sterling automobile are made at the same factory by the same workers in England and the Acura has excellent customer satisfaction while the Sterling does not. These are examples of manufacturing situations, where the first example is one of the same product design made in different factories by different workers, and the second example is one of two different product designs made in the same factory by the same workers. These two examples eliminate manufacturing as the prime suspect in understanding Japanese product quality and leave product design as the item to be investigated in understanding the source of Japanese product quality.

Dr. Genichi Taguchi (3) of Japan is the originator of what has been called "Taguchi Methods" and generally these methods are discussed when the topic of designing quality into Japanese products is reviewed. The uniqueness of Dr. Taguchi's approach to quality problems was in using design of experiments to realize optimum parameter settings during the product design stage itself. The products then needed those parameter settings duplicated in every one manufactured. Dr. Taguchi writes that the goal of product design is to design products that have reliable, stable, and consistent performance in the field, while using inexpensive and highly variable components - high quality at low cost. He illustrates this with an example of a power circuit in a television to generate 115 $\pm$ 1.4 volts DC from 100 volts AC input. An inexpensive and highly variable transistor and a resistor (both low cost) were used in place of a single low variability transistor (high cost) to realize a stable and consistent output.

One way we can attempt to understand Japanese product design is by examining Japanese products. I had examined two equivalent and interchangeable electric relays, one made in Japan and the other one made in the US, and found that the Japanese relay contained more parts than the American relay (Japanese: 92 parts vs. American: 58 parts). There was adjustability of assembly and overdesign in the critical areas of the Japanese relay - slots and fasteners in the arms to align the contacts as opposed to an one-piece molded sub-assembly in the American relay with the possibility of contact misalignment during molding, and more contact material. Even the restoring spring had a more stable configuration than the corresponding spring in the American relay - bigger wire and spring diameters.

The read/write head system in a disk drive has a compression spring that has to deliver a nominal (target) load of 15 grams. The specification for the spring force in the magnetic disk drive industry is 15 grams $\pm$ 2 grams. Product design goal would be to design a spring that delivers the load as close to 15 grams as possible, recognizing that the read/write head system is a critical area. I had seen a Japanese disk drive which had a spring configuration that could deliver a stable and "closer to nominal" load always. This spring was bigger than the spring in the corresponding American disk drive, in terms of spring

diameters and also longer, had a softer spring rate, and could accommodate larger variations.

COMPRESSION SPRING EXAMPLE

In this paper, I am reporting on what I have observed in Japanese products and am attempting to reconstruct what the Japanese product design engineer could be doing to provide components with stable and consistent performance. The coining of the words "design research" have intrigued me somewhat as Dr. Taguchi uses them in several places in his book (3). It is common knowledge that the initial designs for products made by Japanese companies came from American and European companies through collaborations or licensing and I am of the opinion that "design research" was coined as attempting to research the original product design to improve it into a more stable and consistent performance one.

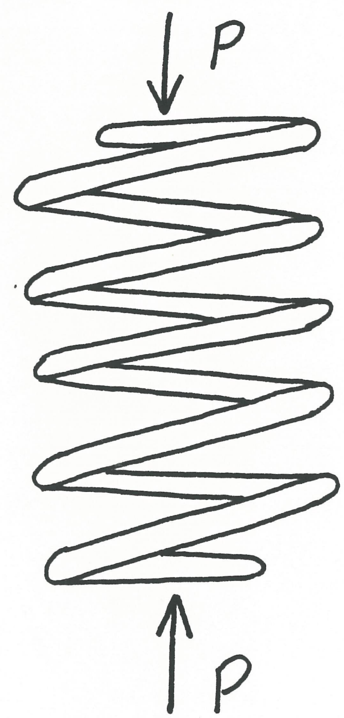
We shall consider the design of a compression spring in order to understand design research. Table 1 gives the parameters for two compression springs, along with the formulas (4) for their calculation. Both these springs are capable of delivering a nominal load of 1 pound (lb.) at a compression of 0.3 in. Table 2 shows calculations of load for spring #1, taking into account variations in the spring diameter and wire diameters only (spring length is ignored for illustration purposes). We observe that as we move closer to the nominal values by reducing variation, the value of the load comes closer to 1 lb.; the nominal value. The question in design research is about how the spring can be redesigned to deliver a load closer to the nominal value with a wider variation in parameters. Table 3 shows the calculations for spring #1 with increase in the number of turns, spring length, spring diameter, and wire diameter, resulting in what is labeled in the table as "design research spring". Observe the reduction in the stress level. If we did not perform design research calculations to improve spring #1, we would have selected spring #2 as the better one because of its lower stress level. Stress plays an important part in the field survival of any component, and the lower the stress level, the better it is. With the calculations showing how spring #1 can be improved, we look at the difference between the original spring #1 and the design research spring #1 with a coil missing. It is not unreasonable to expect the spring winding machine to miss a wind, considering the large quantities of springs that are made. The load in the original spring falls to 0.5 lb. and the load in the refined spring falls to 0.92 lb. still closer to the nominal. If the load specification was in a range of 0.9 lb. to 1.1 lb., the refined or design research spring would still work. Such are the kind of refinements expected in product designs to deliver consistent and stable performance despite large variations (one coil missing in a spring normally renders it useless). Note that for the springs in our example, the alternative approach of preselecting a lower stress level such as 40000 psi would have given us a spring such as spring #2, which would still fail with one coil missing (0.62 lb.).

Table 1. Compression springs to deliver 1 lb. load at .3 in. compression.

Parameter	Spring #1	Spring #2
Outer diameter of spring (in.), D	.240	.312
Wire diameter (in.), d	.020	.026
Spring length (in.), L	1.000	1.000
Load (lb.), P	1.000	1.000
Deflection (in.), f	.300	.300
Shear modulus (psi), G	10×10^6	10×10^6
Stress (psi), S	79196	46861
Spring rate (lb./in.), R	3.33	3.33
Number of coils, n	5.635	7.325
Spring index, c	11	11
L/d ratio	4.16	3.21

Note: .2% set removed for both springs.

Compression spring formulas.



$$P = \frac{f d^4 G}{64 n r^3}$$

$$S = \frac{16 r P k}{\pi d^3}$$

$$k = \frac{4c-1}{4c-4} + \frac{0.615}{c}$$

$$c = \frac{2r}{d}, \quad r = \frac{D-d}{2}$$

Where,

P = load, lbs.
S = stress, psi
G = shear modulus, psi
d = wire diameter, in.
r = mean radius of coil, in.
n = number of coils
f = deflection, in.
k = stress correction factor
c = spring index
D = outer diameter of spring, in.

Table 2. Load in compression spring #1 with variation in spring outer diameter and wire diameter.

Table 2a.

Parameter	.210 (2r)	.230 (2r)
.018 (d)	.75 lb.	.57 lb.
.022 (d)	1.68 lb.	1.28 lb.

Table 2b.

Parameter	.215 (2r)	.225 (2r)
.019 (d)	.87 lb.	.76 lb.
.021 (d)	1.30 lb.	1.13 lb.

Table 3. Design research calculations for spring #1.

Parameter	Spring #1	Increase n	Increase n, d	Increase n, d, D	Design research spring	One coil missing in spring #1	One coil missing in design research spring
Length (L)	1.000	1.106	.970	1.051	1.257	.823	1.166
Outer diameter (D)	.240	.240	.240	.260	.300	.240	.300
Wire diameter (d)	.020	.020	.022	.022	.024	.020	.024
Load (P)	1.000	1.000	1.000	1.000	1.000	.498	.920
Number of coils (n)	5.635	7.635	7.635	7.635	11.000	4.635	10.000
Stress (S)	79196	79196	59746	64488	57145	79196	57145
Deflection (f)	.300	.406	.270	.351	.557	.123	.466
Spring rate (R)	3.33	2.46	3.70	2.84	1.793	4.08	1.973

Note: Formulas for length changes in compression spring are omitted by author.

CONCLUSION

Japanese product quality's source is in design and thus the work in Japanese product design merits investigation and understanding. We have seen in the simple example of the compression spring how the design can be refined to realize a more forgiving component. Japanese product design has been neglected in literature on quality and the best way to learn about it is by examining Japanese products to identify component and product details that result in stable and consistent performance. One cannot claim to have understood Japanese product quality without understanding the work done in product design. To neglect or ignore the work done in Japanese product design is to leave the quality gap wide open and never close it.

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